MILLIMETER WAVE TRANSMITTER USING OPTRICAL HETERODYNING

TECHNICAL FIELD

5   The present invention relates to a device for information transmission and/or reception by means of millimetre waves, i.e. electromagnetic waves corresponding to frequencies of 30 to 300 GHz.

In particular, the present invention relates to a device
10   constituted by an opto-electronic circuit and the corresponding module that uses the device.

BACKGROUND ART

Devices able to generate millimetre waves are known in the art.

15   For instance, negative resistance devices such as Gunn diodes and Trapatt and Impatt devices are known.

In such devices, as the usage frequency increases, the generated electromagnetic signal has progressively decreasing power and progressively broadened frequency band or emission
20   line, so that such devices are unusable for millimetre waves corresponding to frequencies equal to or greater than 60 GHz.

Also known in the prior art are devices able to transmit millimetre waves that do not suffer from the aforementioned problem.

25   For instance, US Patent 5,998,781 discloses an opto-electronic integrated circuit or OEIC for generating and transmitting millimetre waves, comprising a ring laser circuit able to generate optical pulses and a photo-diode able to convert the optical pulses into electromagnetic waves
30   whose frequency corresponds to millimetre waves.

The known OEIC device, however, is only an oscillator device and therefore it cannot be used to transmit information.

In particular, the known device cannot modulate the optical carrier with information constituted, for instance, by voice

and/or data, and transmit the corresponding modulated electromagnetic signal.

Moreover, the aforementioned patent does not provide any indication for making OEIC devices able to receive the modulated electromagnetic signal and to extract, by demodulation, the information contained therein.

DISCLOSURE OF THE INVENTION

An aim of the present invention is to obtain a device able to transmit and/or receive modulated electromagnetic signals in the frequency range of 30 to 300 GHz without encountering the typical problems of Gunn diodes or of equivalent devices.

An aim of the present invention is also to obtain an integrated OEIC device able both to transmit and to receive electromagnetic signals modulated on millimetre waves.

The aims are achieved by the device for transmitting and/or receiving information by means of millimetre waves as claimed.

In particular, according to a first characteristic of the present invention, the OEIC device according to the invention comprises means able to modulate and demodulate respectively signals transmitted and received on carriers at high frequency (30-300 GHz).

According to another characteristic of the present invention, the millimetre wave transmission and reception functions are integrated in a single transceiver device.

BRIEF DESCRIPTION OF DRAWINGS

This and other characteristics of the present invention shall become more readily apparent from the following description of a preferred embodiment, provided purely by way of non limiting example with the aid of the accompanying drawings, in which:

Fig. 1 shows an integrated device for transmitting information by means of millimetre waves, according to the invention;

Fig. 1a shows a section of the device of Fig.1 according to a plane A-A;

Fig. 1b shows a section of the device of Fig.1 according to a plane B-B;

Fig. 2 shows the integrated device for receiving information by means of millimetre waves;

Fig. 3 shows an integrated device for transmitting and receiving information by means of millimetre waves;

Fig. 4 shows an electrical diagram of a part of the transmission and reception device of Fig. 3;

Fig. 5 shows a block diagram of a module for local area network comprising the device of Fig. 3.

In the figure, as shall be readily apparent to a person versed in the art, identical numerical reference correspond to equivalent devices, circuits or functions.

BEST MODE FOR CARRYING OUT THE INVENTION

With reference to Fig. 1, the transmitter device according to the invention (transmitter) 1 comprises a known antenna 30, and an integrated circuit having a substrate 18 (Fig. 1, Fig. 1a, Fig. 1b), preferably made of semiconductor material, for instance Gallium Arsenide (GaAs) or Indium Phosphide (InP) whereon are obtained, by known techniques of growing epitaxial layers, a laser circuit or element (laser) 13 incorporating a saturable absorber 12a, an amplifier circuit or modulating element 15 and a photodiode circuit or element (photodiode) 17, as shall be described in detail hereafter.

For instance, the substrate 18 (Fig. 1, Fig. 1a, Fig. 1b) is constituted by GaAlAs-GaAs-GaAlAs or InP-InGaAsP-InP composition material which, appropriately doped, are able to allow the realisation of p or n layers and p-n or n-p

junctions in order to obtain the elementary circuits according to the invention.

In particular, starting from the n substrate 18, active p guides 20 and 23 are created, able to constitute, in known fashion, optical guides.

Between the active guides 20 and 23 are obtained, in known fashion, one or more quantum wells 22 able to improve the performance of the active guides 20 and 23, increasing the photo-emission efficiency.

For example, the guide 20 is shaped as a channel or rib in order to act as a wave guide.

The structure of the integrated circuit is completed with contacts 19 and 21 for the photodiode 17, contacts 16a and 10a for the amplifier 15, contacts 10 and 10a for the laser 13 and contacts 11 and 10a for the saturable absorber 12a; in particular, the contact 10a is in common with the laser 13 and the amplifier 15.

The laser 13, for example of the ring type, as shown in Figure 1 or, alternatively, of the linear type, for instance Fabry-Perot (FP) or Distributed Bragg Reflector (DBR), is obtained, in known fashion, in the substrate 18 and it is able to generate and transmit optical signals (optical carrier).

According to a preferred embodiment, the laser 13 comprises a guide (laser guide) 12, a first contact 10 able to constitute the anode of the laser 13, a second contact 10a able to constitute the cathode of the laser and situated under the substrate 18 (Fig. 1b), a saturable absorption area 12a, of a known type, having an associated contact 11, separate from the first contact 10 in order to assure that the laser 13 operates in passive mode-locking, as is readily apparent for a person versed in the art.

The laser 13 is coupled, in known fashion, to a wave guide 14, whose geometry is identical to that of the laser guide 12

and able to serve the function as output coupler, i.e. to extract part of the power from the laser 13.

The amplifier circuit 15, characteristic element of the present invention, is associated to a part of the wave guide 14, and comprises an amplification section 16, the contact 16a and the contact 10a, in common with the laser 13, able to bias the amplifier and to insert the modulation signal.

The amplifier circuit 15, thus obtained, is able to serve the function of modulator: applying between the contact 16a and the contact 10a (modulation elements) a current I_e proportional to a modulation signal, for example a modulating signal in a frequency range around 100 MHz, it is possible to vary in corresponding fashion the optical signals generated by the laser 13.

In particular the current I_e, if positive, is able, for example, to allow the passage of the optical signals and, if negative, is able to prevent their passage.

Therefore, by adjusting the intensity of the current I_e, according to useful information to be transmitted, it is possible to modulate in amplitude the optical carrier generated by the laser 13.

The modulating signal can be both analogue and digital, without thereby departing from the characteristics of the present invention.

The photo-diode 17 (Fig. 1a), of a known kind, comprises the contacts 19 and 21, able to constitute respectively the anode and the cathode of the photodiode. They are insulated from each other through a layer of insulating material 24 and are connected to respective terminals 30a and 30b of the antenna 30. In the photodiode 17 the guides 20 and 23 are separated from the substrate 18 by means of a diffusion area 26 of the n^+ type able to lower the series resistance of the photodiode. The photodiode 17 is able to convert the

modulated signal into electromagnetic signals whose frequency corresponds to the millimetre waves.

The photodiode 27 is able, as is well known, to convert the optical modes generated by the laser 13 into millimetre waves
5   at a frequency of c/np in which c is the speed of light, n is an indicative parameter of the index of refraction of the optical guide and p is the perimeter (in this case of the ring laser) or twice the length (in the case of linear FP or DBR laser) of the laser 13.
10   The antenna 30, of a known type, is able to transmit, by means of the terminals 30a and 30b, the millimetre electromagnetic waves generated by photo-diode 17.

In accordance with a second embodiment, the device constitutes a receiver device (receiver) 2 (Fig.2) and
15   comprises an antenna 40, a laser circuit 13, whose shape and characteristics are equivalent to those described for the transmitter 1 (Fig.1, Fig.2) and a photodiode circuit (photodiode) 27, connected to the laser 13 by means of a wave guide 20.

20   The antenna 40, of a known type, has two terminals 40a and 40b equivalent to those described for the transmitter 1, and is able to receive modulated millimetre waves transmitted, for instance, by the transmitter 1.

Between the laser 13 and the photodiode 27 is interposed,
25   in a preferred embodiment not shown in Figure 2, an amplifier in case the power emitted by the laser is not sufficient to bring the photodiode to work in non-linearity area. In this case, between the contacts of the amplifier a continuous bias is applied.
30   The laser 13 is able to generated, in known fashion, longitudinal optical modes, for instance two optical modes, respectively E1 and E2, and to transmit them, by means of the guide 20, to the photodiode 27. In the photodiode 27, the two

optical modes are subject to optical beat generating an electrical signal at the desired frequency (30-300 GHz).

The photodiode (receiving signal) 27 comprises an anode
19 and a cathode 21 connected to the antenna terminals 40a

5   and 40b and equivalent to those described for the photodiode
17, but it is associated, according to a characteristic of the present invention, through the anode 19 and the cathode 21 to a biasing system or bias elements able to make the photodiode itself 27 operate both as a photodiode and as a

10   diode, as will be described in detail hereafter, in such a way as to reveal or detect information corresponding to the modulation component of the received signal and allow to receive and process useful information transmitted by means of millimetre waves.

15   This effect is readily apparent from the mathematical expressions indicated hereafter, verified experimentally, which clearly demonstrated that that modulation component of the received signal can be reconstructed on the basis of the signals collected and transmitted by the anode 19 and by the

20   cathode 21 (detecting elements) of the photodiode 27 to a signal processing circuit as described in detail hereafter.
The photodiode 27 is able, as is well known, to convert the optical modes generated by the laser 13 into millimetre waves at a frequency of c/np in which c is the speed of light, n is

25   an indicative parameter of the index of refraction of the optical guide and p is the perimeter (in the case of ring laser) or twice the length (in the case of linear laser FP or DBR) of the laser 13.
In the embodiment described below, for the sake of

30   simplicity, only two optical modes are considered, although the optical modes generated by the laser 13 can be more than two. In this second case, however, the example can always be brought back to the two optical modes alone, as is readily apparent to the person versed in the art.

Moreover, for the sake of greater clarity, in the following expression the modulating signal is not shown.

As is well known, the two optical modes can be represented mathematically by means of the following expressions:

$$E_1 = E_{10} \exp i2\pi f_1 t + \theta_1 \qquad (1)$$

$$E_2 = E_{20} \exp i2\pi f_2 t + \theta_2 \qquad (2)$$

in which E_{10} and E_{20} are the amplitudes of the optical modes generated by the laser 13, f_1 and f_2 are the frequencies of the waves, $[f_1 - f_2 = c/np,]$ and θ_1 and θ_2 are the optical phases of the optical modes or ranges.

The photodiode 27 is able to generated, for two optical modes, a photo-current equal to:

$$I_{ph} = \langle |E_1 + E_2|^2 \rangle, \qquad (3)$$

in which the bars conventionally indicate the module, and the parentheses <..> indicate the time average, so that, by simple replacement, one obtains:

$$I_{ph} = E_{10}{}^2 + E_{20}{}^2 + 2 E_{10}E_{20} \cos 2\pi(f_2 - f_1) t + \theta_2 - \theta_1$$

$$= I_{ph0} \cos 2\pi(f_2 - f_1) t + \theta_2 - \theta_1 \qquad (4)$$

As will be readily apparent to a person versed in the art, the first two terms of the expression (4) represent continuous components, the third shows a beat signal at a frequency of $f_1 - f_2 = c/np$.

In the case of the signals received by the antenna 40, said signals can be represented as

$$e_{mm} = e_0 \cos 2\pi f_{mm} t \qquad (5)$$

Said signals are able to generate in the photodiode 27 a current equal to:

$$i_{mm} = [e_0/(Z_A+Z_{ph})]\cos 2\pi f_{mm}t \qquad (6)$$

in which Z_A and Z_{ph} are the impedance of the antenna and the dynamic impedance of the photodiode.

Since the voltage-current characteristic of the photo-diode is not linear, the superposition of the photo-generated current I_{ph} and of the current i_{mm} received from the antenna 40 gives rise to an electrical beat.

Representing the voltage-current characteristic of the photodiode as:

$$I_{tot} = I_0[\exp(qV/\eta kT)-1]-I_{ph} \qquad (7)$$

in which V is the voltage applied to the photodiode, I_0 is the inverse current, q is the charge of the electron, η is the ideality of the junction, kT=25 meV is the equivalent temperature energy and I_{tot} is the total current through the photodiode. For $I_{tot}=i_{mm}$ one finds that the voltage V between anode and cathode 21 is:

$$V = (\eta kT/q)\{1 + \ln(I_{ph} + i_{mm})/I_0\} \qquad (8)$$

said voltage, ignoring the continuous term and developing the logarithm to the second order (as log (1+X) = $1+X^2/2$) becomes:

$$V = (\eta kT/q)\{1 + (I_{ph} + i_{mm}-I_0)^2/2\ I_0^2\} \qquad (9)$$

and replacing the expressions of I_{ph} and i_{mm} one obtains:

$$V = (\eta kT/q)\ 2I_{ph0}i_{m0} \cos 2\pi(f_1 - f_2 - f_{mm})t$$

$$= (\eta kT/q)\ 2\ I_{ph0}i_{m0} \cos 2\pi(c/np - f_{mm})t \qquad (10)$$

Briefly, from the final expression 10 it emerges, in accordance with the present invention, that the voltage at the ends (19, 21) of the photodiode 27 contains the demodulated component of the received signal.

In other words, thanks to the non linearity of the characteristic of the photodiode 27 it is possible to extract from the contacts 19 and 21 (detecting elements) a voltage that, appropriately processed by means of an electronic circuit 70 (Fig.4) associated, for instance, to the contacts of the receiver 2 (Fig.2), allows to reconstruct or demodulate the modulation component of the received signal, i.e. the useful information of the received signal.

The non linearity of the characteristic of the photodiode is maximised, for instance, appropriately selecting the working point of the photodiode by means of a bias voltage V_{bias} applied thereto. In most photodiodes available from normal manufacturers, the maximum of the demodulated signal is obtained experimentally using a V_{bias} of +200 ÷ +300 mV, i.e. such as to bring the photodiode into slight direct bias.

This voltage is applied to the photodiode by means of a series resistance, in a manner that is obvious to a person versed in the art.

In accordance to a variation, readily understandable for a person versed in the art, the receiver device 2 can also be configured solely to receive non modulated millimetre waves.

In this type of solution, too, the photodiode 27, biased in conditions of non linearity, is able to detect the millimetre waves received by means of the antenna terminals 40a and 40b.

According to a third embodiment, the device constitutes a transceiver device (transceiver) 3 (Fig.3), resulting from the combination of the devices 1 and 2 (Fig.1, Fig.2), as

described, and comprises an antenna 40, a laser 13, a first photodiode 17 connected to the antenna 40 and used to transmit the modulated signal and a second photodiode 27 connected to the same antenna and used to receive the
5   modulated millimetre wave signal. The first photodiode 17 and the second photodiode 27 are connected to the laser 13, respectively, by means of a first amplifier circuit 15 and a second amplifier 25 and a coupler 50 that allows to insert the signal generated by the laser 13 both in the first
10 photodiode 17 and in the second photodiode 27. In the photodiode 17, by optical beat, a photo-generated current is generated at a frequency corresponding to the selected millimetre wavelength, with superposed the modulating signal obtained by varying the gain of the amplifier 15. Said
15 current is used as the driving current of the antenna. In the second photodiode the photo-generated at the frequency of the millimetre wave carrier is used to move to the base band the signal received through the antenna through an electrical beat obtained by means of the non linear characteristic of
20 the photodiode made to operate simultaneously also as a mixer diode, by means of appropriate bias applied through the contacts 38 and 39 as described previously for the receiver of Figure 2.

      In order to combine the functions of the transmitter 1
25 with those of the receiver 2 in a single transceiver device 3, a device having a resistor bridge electrical arrangement (Fig.4) is proposed herein as a preferred embodiment. As other embodiments, it would be possible to use couplers or circulators for millimetre waves.
30 In accordance with said arrangement, the first photodiode 17 (Fig.3, Fig. 4) and the second photodiode 27 are positioned on opposite diagonals of the resistor bridge comprising respective resistors 32, 34, 36, each having characteristic impedance equal to that of the antenna 40.

Thanks to said arrangement, the photodiodes 17 and 27 are
connected to the same antenna 40 (which operates both in
transmission and reception), but the exchange of the signals
between the first photodiode (transmission photodiode) 17 and
5   the second photodiode (reception photodiode) 27 is nil, as
will be readily apparent to a person versed in the art.

      In particular, the transceiver 3 comprises, in addition
to the circuit elements described above, for the transmitter
1 and the receiver 2, the resistors 32, 34, 36 in which the
10   resistor 32 is connected between the anode of the photodiode
17 and the anode of the photodiode 27, the resistor 34 is
connected between the anode of the photodiode 17 and the
cathode of the photodiode 27 and the resistor 36 is connected
between the cathode of the photodiode 17 and the cathode of
15   the photodiode 28. The disposition of the resistors is
optimised to reduce the distance between the contacts to be
connected in order to reduce the effect of parasitic
capacities.

      The transceiver 3 is, therefore, able both to transmit
20   and to receive useful information and, therefore, it can be
used, for example, as a basic circuit element for a
transceiver electronic module (module) 5 (Fig. 5) in a
wireless millimetre wave local area network (local area
network), as described in detail hereafter.

25   In this case as well, in accordance with a possible
variation readily understandable to a person in the art, the
transceiver device 3 can be used alternatively to transmit
and receive non modulated millimetre waves, simply not
applying modulation signals to the first amplifier 15 and
30   revealing only the millimetre waves at the ends of the second
photodiode 27.

For instance, the module 5 comprises a first electronic
circuitry 60, of a known type, connected in input, to the
contacts 16a and 10a of the amplifier 15 of the transceiver 3

and able to generate, on the basis of useful information to be transmitted, a modulating signal I_e (IN-MOD) to be transmitted superposed to the millimetric carrier.

Moreover, the module 5 comprise a second electronic circuitry 70, of known fashion, connected in output, to the contacts 31 and 37 of the receiving photodiode of the transceiver 3 and able to process the output signal (OUT-MOD) implementing the function of extracting the useful information based on the expression [10]; in other words, the electronic circuitry 70 is able to reconstruct or demodulate the useful information, based on the output signal (OUT-MOD) from the transceiver 3.

Clearly, also the transmitter 1 and the receiver 2, appropriately coupled, can be used to obtain a wireless local area network, as is readily apparent to a person versed in the art.

The devices and modules according to the present invention have been described taking as a reference millimetric waves in the frequency range between 30 and 300 GHz, but nothing prevents the extension of their use both to lower frequencies, range in which said solution could be uneconomical, and to higher frequencies, range in which current technological limitations and the lack of adequate measuring instrumentation prevent a punctual certification.

Obvious modifications or variations are possible to the above description, in dimensions, shapes, materials, components, circuit elements, connections and contacts, as described in the details of the circuitry and of the illustrated construction and of the method of operation without thereby departing from the spirit of the invention as set out by the claims that follow.